FATE OF DIELDRIN IN SEDIMENT, WATER, VEGETATION, AND INVERTEBRATES OF A SLOUGH IN CENTRAL ALBERTA, CANADA

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Quaestiones Entomologicae
11: 69 - 96 1975

Sufficient dieldrin was applied in July, 1967 to a slough in central Alberta, Canada to give a concentration of approximately 1 ppb in water. Dieldrin concentrations in mud, water, vegetation, and invertebrates were monitored by gas chromatography until fall, 1968. Residues were undetectable in mud, water, and vegetation by the spring of 1968 but persisted at low levels in resident invertebrate populations throughout the remainder of the study, final concentrations varying from 1.8 to 44.6 ppb. Resident primary and secondary invertebrate consumers carried similar levels of dieldrin in their tissues.

The fate of chlorinated hydrocarbon insecticides in mud, water, vegetation, and invertebrates as determined in this study is compared with the results of similar studies.

Une concentration approchant une partie par milliard de dieldrin dans l'eau d'un marais du centre de l'Alberta tut appliquée en juillet, 1967. Les concentrations dans le lit beueux l'eau, la végétation et les invertébrés tu rent analysées par chromatographie gazeuse jusqu'à l'automne de 1968. Aucun residu ne tut décelé dans la boue, l'eau et la végétation au printemps de 1968, mais une concentration très basse (concentrations finales variant entre 1.8 et 44.6 parties par billions), a persisté dans les populations des invertébrés résidants pendant le reste de l'étude. Les invertébrés consomateurs primaires et secondaires résidant dans le marais ont démontré des taux similaires de dieldrin dans leurs tissues.

Le sort des insecticides d'hydrocarbons chlorinés dans la boue, l'eau, la végétation et les invertébrés comme déterminé dans cette étude est comparé aux résultats d'études similaires.

INTRODUCTION

Community studies dealing with the effects of chlorinated hydrocarbon[1] insecticides on the diversity of freshwater invertebrates are common. Studies on flowing water systems include those of Ide (1957), Corbet (1958), Bridges and Andrews (1961), Frey (1961), Hynes and Williams (1962), Moye and Luckmann (1964), Hitchcock (1965), Dimond (1967), Hatfield (1969), Fredeen (1972), and Wallace et al. (1973). Lentic studies include those of Grzenda, Lauer, and Nicholson (1962), Jones and Moyle (1963), Edwards et al. (1964), and Kennedy, Eller, and Walsh (1970).

In general, these studies deal with relatively high concentrations of pesticides and the invertebrates are not analyzed for residue levels. Unfortunately, studies of the effects of pesticides on the diversity of freshwater invertebrates are separate from studies of residue levels. In addition, the effects of dieldrin, a once common agricultural insecticide, on aquatic communities have not been studied.

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1. I use "chlorinated hydrocarbons" to designate DDT and its related compounds, the cyclodienes (excluding toxaphene which is not a true cyclodiene; O'Brien, 1967), polychlorinated biphenyls (PCB's), and the hexachlorocyclohexanes.

With the advent of more sensitive analytical techniques (Moore, 1967; Edwards, 1970; Chesters and Konrad, 1971; Cope, 1971; Muirhead-Thomson, 1971) and the creation of national pesticide surveillance programs (Breidenbach and Lichtenberg, 1963; Stickel, 1968; Edwards, 1970; Chesters and Konrad, 1971) pesticide residues have been detected in concentrations of tens of parts per billion and less in water (Breidenbach and Lichtenberg, 1963; Tarzwell, 1965; Westlake and Gunther, 1966; Edwards, 1970; Chesters and Konrad, 1971; Muirhead-Thomson, 1971); bottom sediments (eg. Morris and Johnson, 1971); and fish (e.g. Fredeen, Saha, and Royer, 1971). Of these residues, dieldrin is widespread and common (Buescher, Dougherty, and Skrinde, 1964; Green, Gunnerson, and Lichtenberg, 1967; Moore, 1967; Stickel, 1968; Edwards, 1970; Chesters and Konrad, 1971). The persistence of dieldrin in the environment has long been known from field studies. Mackay and Wolkoff (1973) have shown mathematically that the persistence of dieldrin in water was the longest of several compounds examined (two alkanes, six aromatics, four pesticides, four PCB's, and one mercury). Its potential evaporation half-life in 1 m^3 of water at 25 C was 723 days. Mackay and Wolkoff (1973) also noted that evaporation rates in the environment may be substantially slower, making dieldrin one of the most persistent environmental contaminants.

Unfortunately, the literature on the effects of pesticides on fauna is fraught with generalities. There exists a belief that the use of pesticides automatically implies an effect on diversity (e.g. Moore [1967]; p. 111, 113, 114, 125). If such is the case, the need to determine the levels of pesticides in fauna that will cause diversity changes is obvious. Tarzwell (1965), Moore (1967), and Stickel (1968) discussed this point but only indirectly. However, with respect to DDT in Maine forests, Dimond (1969, p. 5) stated: ". . . thresholds for such [sublethal] effects are not known. This aspect of the problem needs thorough study in the immediate future." Cocks (1973, p. 149) noted that "The biological effects of low doses of pesticides are at present poorly understood". Edwards and Thompson (1973) noted that only sparse evidence exists on the effects of sublethal doses of pesticides on soil inhabiting invertebrates. Menzie (1972, p. 216) stated: "We have only scratched the surface in understanding the significance and the effects of low levels of pesticides."

Trophic level effects (i.e. the concentration of pesticides along food chains) are a commonly reported result of pesticide use (e.g. Hunt and Bischoff, 1960; Pillmore, in Rudd, 1964; Bridges, Kallman, and Andrews, 1963; Hickey, Keith, and Coon, 1966; see also reviews by Moore, 1967; Newsom, 1967; Stickel, 1968; Edwards, 1970; and Cope, 1971) and are an important aspect of studies of the effects of chlorinated hydrocarbon insecticides on faunal diversity. However, the study of trophic level effects solely in invertebrates has been neglected.

In 1966, an experiment was begun to examine the effect of a single small addition of dieldrin to a slough in central Alberta, Canada. The major objectives were to determine the persistence of dieldrin in the aquatic ecosystem, whether the chemical became concentrated in higher trophic levels of the invertebrate community, and whether such an application had a significant effect on the diversity of the aquatic invertebrates. The results of the first two objectives are presented in this report.

METHODS

Introduction.

The occurrence of dieldrin residues in the water, substratum, plants, zooplankton, and benthic invertebrates was measured in two sloughs in central Alberta, Canada: a control slough to which no dieldrin was added and an experimental slough to which enough dieldrin was added in July, 1967 to give a concentration of approximately 1 ppb in water.

Dieldrin was used because of its widespread and common occurrence in freshwater ecosystems,

and because of its persistence. A concentration of 1 ppb in water was chosen because it was well below dieldrin LC_{50}'s for a number of aquatic invertebrates (Rosenberg, 1973). This concentration fulfilled the requirement of low level dieldrin contamination and ensured that mass kills of fauna did not occur. Sloughs were chosen as the experimental sites because they are a common feature of the Edmonton area, they sometimes receive runoff containing pesticides (see Westlake and Gunther, 1966; Van Middelem, 1966), and because their relatively small size makes community studies more manageable in a practical sense.

Description of study site.

As dieldrin was at no time during the study detected in any of the samples from the control slough, this slough will not be discussed further here. A detailed description of the control slough is given in Rosenberg (1973).

The experimental slough (hereinafter called "D") is located in the parkland area of central Alberta in the County of Strathcona approximately 14.5 km southeast of the city of Edmonton and in an area of mixed farming. It is at 113° 22′ 08″ W, 53° 25′ 27″ N, approximately 738 m above sea level, and has an area of approximately 1 ha. The surrounding terrain has rolling moraines and kettlehole sloughs. Bayrock and Hughes (1962) described the geology of the area and Bowser et al. (1962) the soils. For size, shape, and depth contours of D slough as taken at the start of the study see Fig. 1.

Algal blooms occurred during the period May to October over the 3 years of the study. The commonest algae were *Oscillatoria* sp., *Nodularia* sp., and *Mougeotia* sp. In 1966 and 1967 the main blooms occurred during July and August and were over by September. However, in 1968 the main blooms occurred during June and July with a minor bloom (mainly *Oscillatoria* sp.) in August.

The main submergent vegetation was the hornwort (*Ceratophyllum demersum* L.). It was dispersed fairly evenly throughout the slough. Sago pondweed (*Potamogeton pectinatus* L.) was present in 1967. It became more common in 1968. Ivy-leaved duckweed (*Lemna trisulca* L.) was the dominant species of floating vegetation and lesser duckweed (*L. minor* L.) was also present. The emergent vegetation was composed of stands of common cattail (*Typha latifolia* L.), great bulrush (*Scirpus validus* Vahl), and mare's tail (*Hippuris vulgaris* L.) which were discontinuously distributed around the periphery of the slough and faded shoreward into the sedges (*Carex rostrata* Stokes, *C. aquatilis* Wahlenb., and *C. atherodes* Spreng.) and Kentucky blue grass (*Poa pratensis* L.) which in turn continued from the water-land transition onto the land. Among the sedges and grass along the shore were moss, *Drepanocladius aduncus* (Hedw.) Warnst., and liverwort, *Rhicciocarpus natans* (L.) Corda. A typical hydrarch succession was evident in the transition from water to land with *Populus balsamifera* L. being the climax species (Rosenberg, 1973).

There was an overall decline in the level of water in the slough during the 3 years of the study, probably caused mainly by the below-average precipitation over the study period.

Maximum and minimum and surface water temperature regimes are shown in Figs. 2 and 3 respectively. Maximum and minimum temperatures generally increased and decreased respectively throughout the study, probably reflecting the inability of the reduced water volume in the slough to buffer air temperature change. Stratification did not occur.

Since free water was observed in D slough past the end of December in 1966 and 1967, the slough possibly did not freeze to the bottom in the first (1966/1967) or second (1967/1968) winters. Almost certainly, however, D slough totally froze in the third winter (1968/1969) probably because of the much reduced water level.

A Secchi disc could always be seen at the bottom of the deepest part of the slough on a clear day and turbidity levels (measured by the Model DR-EL Direct Reading Engineer's

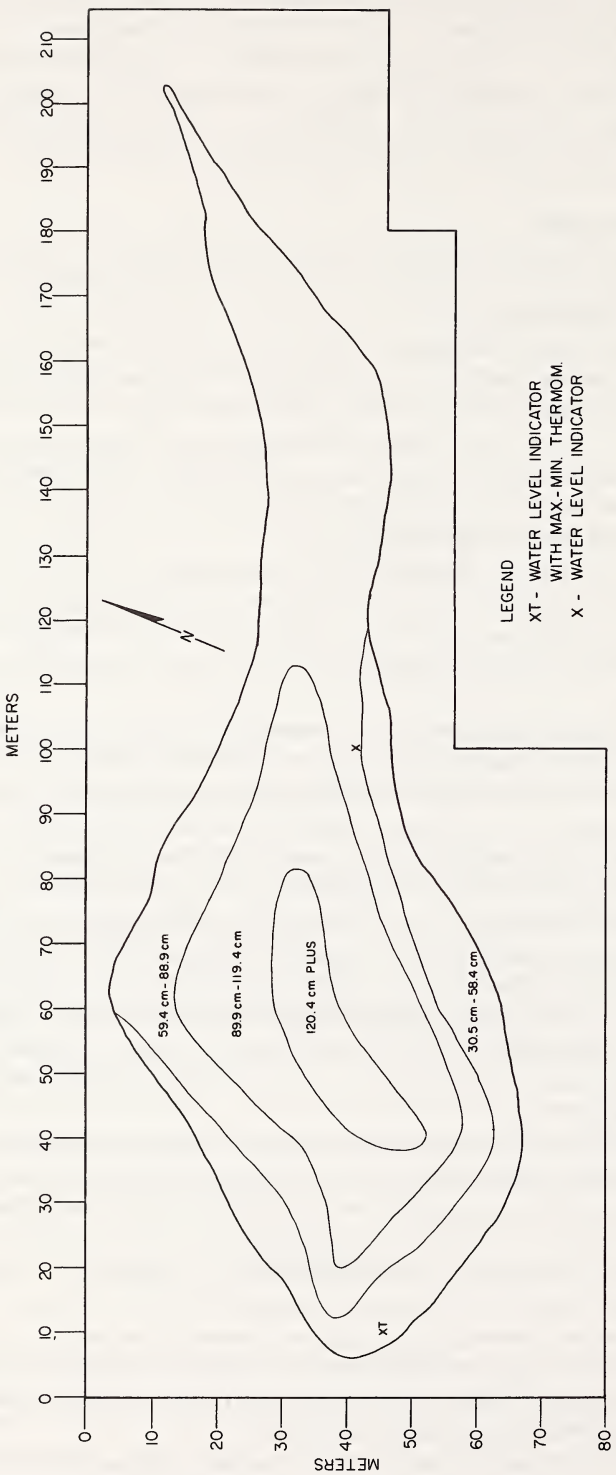

Fig. 1. Size, shape, and depth contours of D slough at the start of the study (end of May, 1966). (Methods according to Welch, 1948).

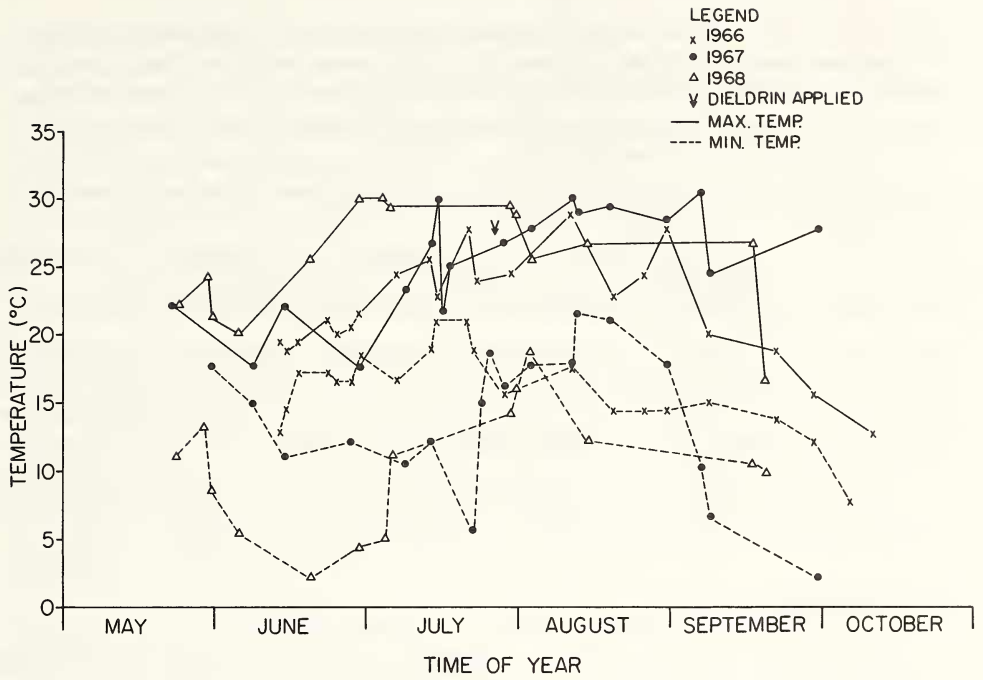

Fig. 2. Maximum and minimum water temperatures in D slough for May to October 1966, 1967, and 1968.

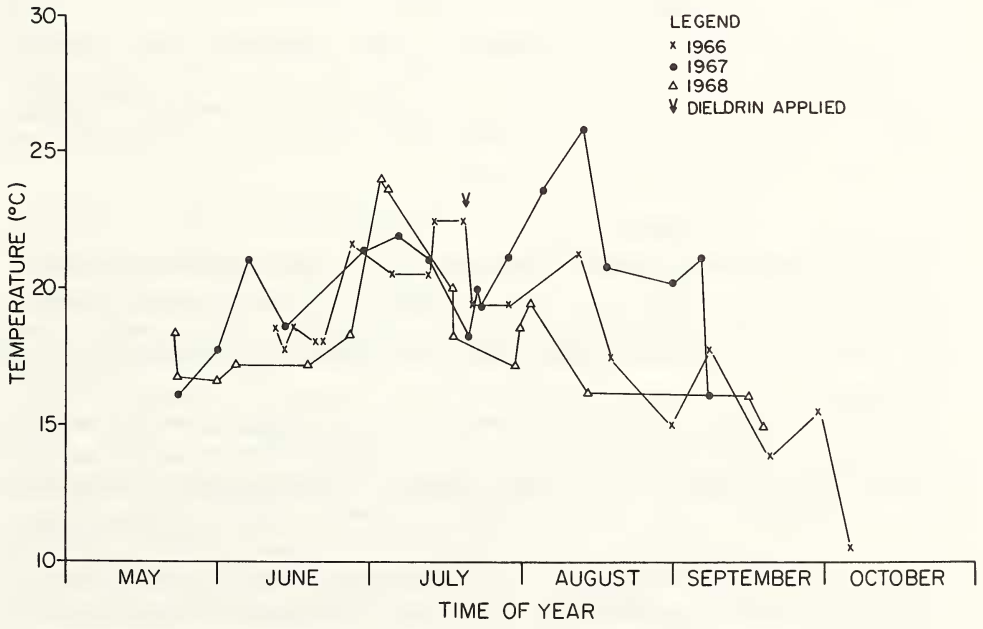

Fig. 3. Mean surface water temperatures in D slough for May to October 1966, 1967, and 1968.

Laboratory Hach Kit; Hach Chemical Co.; Ames, Iowa) were in the 0 to 25.0 ppm range.

Oxygen concentrations (Winkler iodometric method: American Public Health Association, 1960) generally did not exceed 20 ppm. Anaerobic conditions were found in the slough in November and December, September, and February of 1966, 1967, and 1968 respectively. The only evidence of oxygen stratification was during the open-water period of 1967. Oxygen concentrations usually varied among depth classes. Many times during winter sampling H_2S was evident.

Dissolved solids, and other dissolved gases were measured by the Hach Kit. Total hardness was in the 300 to 400 ppm range and the overall mean calcium to magnesium ratio was 1.84. Alkalinity was mainly due to the bicarbonate ion. The pH varied from 7.65 to 9.30 with an overall mean of 8.55. Free CO_2 concentrations were generally within the 0 to 10 ppm range. Values for orthophosphate usually remained below 1.0 ppm throughout the study. Sulphate was the most abundant anion in the slough. Concentrations of sulphate were generally in the 200 to 350 ppm range. Nitrite and nitrate nitrogen were generally in the 0 to 0.02 ppm and 10 to 25 ppm range respectively. Physical and chemical parameters of the water of D slough were similar to those of the slough described by Daborn (1969) and within the ranges reported by Hartland-Rowe (1966) for permanent ponds in the Canadian prairies.

Dieldrin application.

To estimate the volume of water for dieldrin application, the slough was re-surveyed and re-mapped two days before the pesticide was added. Four depth classes were used, and from the formula in Welch (1948), the volume was calculated to be close to 4.0×10^6 liters. As the 0 to 30.5 cm depth class was impossible to delimit in the field, a volume of 4.0×10^6 liters was used.

The dieldrin used (Shell Canada Ltd.) was an emulsifiable concentrate with an average concentration of 0.2×10^6 ppm (Rosenberg, 1973). The amount required to yield a concentration of 1 ppb in 4×10^6 liters of water was calculated to be 22.7 ml.

The pesticide was applied using a compressed air sprayer (Leigh Products Inc., Universal Metal Products Div., Sarnac, Mich.) calibrated to ensure an even flow. The boat was rowed over the slough in patterns meant to yield an even application of the pesticide (Rosenberg, 1973; Fig. 2). The nozzle of the sprayer was held about 5 cm below the water surface to ensure that all the pesticide was added to the slough.

Sampling program for gas chromatography.

Eleven sets of dieldrin analyses were done on mud, water, vegetation, and invertebrates: once before application and eight times after application during the open-water period (at approximately monthly intervals after application until September, 1967, from May to September, 1968, and in June, 1969) (Table 1). Mud and ice were collected on February 9, 1968 and on March 6, 1969.

Mud and water samples were collected from each slough according to a random sampling plan and in proportion to the area being sampled. For the collection of mud, core samples were taken from each quarter of the slough, using a Moore (Phleger) sampler with a glass tube. The corer sampled the top 7.6 to 10.2 cm of the slough bottom. Samples were pooled by quarter and a subsample taken for analysis. Water samples were taken, from the shallowest to the deepest of the four depth classes, with a Kemmerer bottle which was emptied into a 20 liter pesticide-free pail designated for each depth class. A subsample was removed from each pail for analysis.

Four kinds of vegetation were collected for dieldrin analysis: submergent (*C. demersum*), floating (*L. trisulca*), emergent (*C. rostrata*), and algae. Algae samples were collected whenever

possible in 1968 (usually during a bloom). The sampling plan for invertebrates (Rosenberg, 1973) was used to establish the areas from which each type of vegetation was collected. The samples of each type and from each quarter were put into separate plastic freezer bags for return to the laboratory and sub-samples removed from the bags for analysis.

Table 1. Samples taken from D slough during the open-water season for dieldrin analysis.

Date	Number of Days after Application of Dieldrin	Type of Sample						
		Mud	Water	Vegetation*				Invertebrates
				Sub.	Float.	Em.	Algae	
1967								
July 7		+	+					
July 13				+		+		
July 14								+
July 22	1	+	+	+	+	+		
July 23	2							+
August 10	20	+	+	+	+	+		
August 11	21							+
September 6	47	+	+	+	+	+		
September 7	48							+
1968								
May 29	313							+
May 31	315	+	+	+	+	+	+	
July 3	348	+	+	+	+	+	+	
July 4	349							+
July 30	375	+	+	+	+	+		
July 31	376							+
September 17	424							+
1969								
June 2	682	+	+		+**	+		

* Sub. = submergent; Float. = floating; Em. = emergent.

** Mixed with algae.

The mud, water, and vegetation samples were stored at 7 to 8 C and gas chromatographic analysis was usually completed within a few days after their collection.

Sampling of invertebrates was done with a dip net at predetermined locations in the littoral area of each slough (Rosenberg, 1973). Zooplankton was collected with a Wisconsin plankton net. Invertebrates were sorted in the field and were put immediately into a portable freezer containing dry ice. Vials were stored in the laboratory in a -23 C freezer room prior to dieldrin analysis. Chironomid immatures were also collected from unpreserved benthic samples taken with a 15.2 cm^3 Ekman grab (Rosenberg, 1973). Gastropods were collected at random in addition to those collected as described above. While it was unnecessary to make quantitative collections of invertebrates, it was important that enough biomass be collected for gas chromatographic analyses.

Methods for the gas chromatographic analysis of mud, water, vegetation, and invertebrates.

Full descriptions of apparatus, reagents, and procedures are given in Rosenberg (1973). Briefly, water samples were extracted basically according to Breidenbach et al. (1966, p. 22-25) and injected into the gas chromatograph without cleanup. Extraction of mud was done

according to Tyo (unpublished)[2] and cleanup was basically as described in Barry et al. (1968, section 211.15). Vegetation was extracted according to Barry et al. (1968, section 212.13b and 212.15). Cleanup was the same as for the mud samples. Recovery studies using a 1 ppb spike in water, 10 ppb in mud, and 100 ppb in vegetation gave average recoveries (3 replicates) of 86.5, 81.1, and 83.0% respectively.

The confirmatory procedure used involved chemical conversion of dieldrin to a ketone by boron trifluoride etherate (Skerrett and Baker, 1959; J. Singh[3], personal communication).

Published accounts of extraction and cleanup procedures specifically for the gas chromatographic analysis of chlorinated hydrocarbon residues in aquatic invertebrates are rare in the literature. Therefore, a description of the method developed for invertebrates and used in this study is given in Appendix I. To provide maximum sensitivity, invertebrate specimens were pooled wherever necessary and possible (e.g. see Fredeen et al., 1971; Bradshaw et al., 1972). In such instances, attempts were made to keep lower ranking taxa separate but where it was obvious that it would be impossible to detect any residue unless a larger sample was used, lower taxa were combined. Primary and secondary consumers were kept separate (except for one sample of Hirudinea, see Table 9).

An SE30 column in the Varian 2100 gas chromatograph was used as a confirmatory procedure for invertebrate samples additional to a micro-coulometric system and the boron trifluoride conversion (Rosenberg, 1973).

Concentrations of dieldrin in mud, vegetation, and invertebrates are on a wet-weight basis.

RESULTS

No dieldrin was detectable in mud, water, vegetation or invertebrates prior to application. Dieldrin concentrations in the mud and water of D slough after application are shown in Table 2. Residues in mud went below detectable levels between 47 days after application (September 6, 1967) and the next date of sampling, 203 days after application (February 9, 1968). The actual time was probably closer to the first date given because concentrations were less than 1 ppb at that time.

Table 2. Dieldrin concentrations (ppb) in mud and water of D slough$^{\infty}$.

Days after Application	Mud (quarters)				Water (depth classes-cm)			
	SW	SE	NW	NE	30.5-58.4	59.4-88.9	89.9-119.4	120.4 plus
1	4.56	4.70*	3.20		0.21	0.15	0.56	0.46
20	0.54+	<el++	<el	<el	0.12**	0.12	<el	
47	<el	0.53	0.59	0.72	<el	<el	<el	

* Solid underlining = confirmed with boron trifluoride etherate.

** Broken underlining = boron trifluoride etherate conversion unclear due to excessively dirty sample or sample with insufficient dieldrin for confirmatory procedure.

\+ Five times usual volume injected to get value.

++ Below experimental limits of detection.

∞ Corrected to 100% recovery.

2. R. M. Tyo: Pacific Northwest Water Laboratory, Federal Water Pollution Control Administration, U. S. Department of the Interior, Corvallis, Oregon. See Rosenberg (1973) for method.
3. Scientific Services Laboratory, Canada Department of Agriculture, Ottawa, Ontario. See Rosenberg (1973) for method.

Maximum concentrations of dieldrin in water were reached the day after dieldrin application and were below detectable levels shortly after 20 days after application (Table 2).

Residues in the submergent vegetation went below detectable levels some time between 47 days after application (September 6, 1967) and the first sampling of the following spring, 315 days after application (May 31, 1968) (Table 3). As in the mud samples, the time was probably closer to the former because of the relatively low levels present at that time.

Table 3. Dieldrin concentrations (ppb) in vegetation of D slough[∞].

Days after Application	Emergent (quarter) SW	SE	NW	NE	Submergent (quarter) SW	SE	NW	NE	Floating (quarter) SW	SE	NW	NE
1	4.03	12.81+	4.57	5.54, 10.59		41.24	32.55, 58.23*		51.25			18.11
20	7.60	<el++	<el	<el		21.36	19.61		23.68			29.76
47	<el	<el	<el	<el	0.49			0.91		2.78	2.65	

* Solid underlining = confirmed with boron trifluoride etherate.

\+ Broken underlining = boron trifluoride etherate conversion unclear because of excessively dirty sample or sample with insufficient dieldrin for confirmatory procedure.

++ Below experimental limits of detection.

∞ Corrected to 100% recovery.

Dieldrin concentrations in zooplankton were at a maximum on the day after treatment and thereafter they declined steadily (Table 4). The initial concentration of dieldrin was the highest recorded for any ecosystem component for the study. Dieldrin residues were still detectable at the end of the study, 424 days after dieldrin application.

Table 4. Dieldrin concentrations in zooplankton* of D slough.

Days after Application	Sample & Size (g)	Dieldrin Concentration (ppb)	Confirmation Microcoulometric	Boron Trifluoride Etherate
2	0.16	362.88		
21	2.45	41.55	positive	positive
48	No.1 2.04	24.84		
	No.2 3.06	41.31	positive	
349	0.84	5.14		
376	0.52	6.65	positive+	
424	1.17	5.27	positive	

* The samples analyzed were composed mainly of *Daphnia* sp., *Diaptomus* sp., and *Cyclops* sp.

\+ These samples combined to have sufficient weight of dieldrin for confirmation.

Dieldrin concentrations in Gastropoda of D slough are shown in Table 5. A number of samples showed no detectable residues because an insufficient weight of snail tissue was originally used for extraction and cleanup. The negative confirmation for *L. stagnalis* sample number 2 for 348 and 349 days after application and *H. trivolvis* (Say) for 424 days after application was due to the injection of an insufficient volume of sample (and hence weight of dieldrin) into the microcoulometric apparatus. Highest residues generally occurred 2 days after dieldrin application and were still detectable in sufficiently large samples at the end of the study.

Tables 6 and 7 show residue concentrations in the Hemiptera of D slough. Residues in

adult Corixidae and Notonectidae were highest 2 days after dieldrin application. Residues were below detectable levels in the immature corixids 349 days after application (July 4, 1968) probably because the sample used was too small (Table 6). The larger sample of *N. undulata* Say immatures 376 days after application (July 31, 1968) gave positive results (Table 7). However, the absence of detectable levels of dieldrin in adult *C. audeni* Hungerford and *N. undulata* in 1968 probably reflects a true absence because some of the samples analyzed were relatively quite large (see Table 6, 349 days after application; and Table 7, 376 days after application). Adult corixids and notonectids are capable of leaving and entering habitats and so the absence of detectable dieldrin in 1968 is not surprising.

Table 5. Dieldrin concentrations in Gastropoda of D slough.

Days after Application	Species	Sample & Size (g)	Dieldrin Concentration (ppb)	MC*	Confirmation SE30+	Confirmation BF_3 Etherate
2	*Lymnaea stagnalis*	No.1 2.00	105.39	positive		
		2 2.01	114.92			
		3 2.01	111.23	positive		
		4 2.01	121.62			
		5 2.00	162.31			
		6 2.00	193.90	positive		
		7 2.01	198.27	positive		
		8 2.01	200.18			
21	*L. stagnalis*	No.1 2.00	99.01			
		2 2.01	120.28	positive		
		3 2.01	120.37			
	L. elodes	1.33	47.37		positive	
	Helisoma trivolvis	0.69	51.82			
48	*L. stagnalis*	No.1 0.29	145.47			
		2 1.43	10.49		positive	
313	*L. stagnalis* & *L. elodes*	1.71	35.24	positive		
348 & 349	*L. stagnalis*	No.1 6.64	22.31	positive		positive
		2 2.01	4.98	negative		
		3 2.00	< el**	negative		
		4 2.01	< el	negative		
376	*L. stagnalis*	3.50	10.64			
	L. elodes	4.13	9.41			
	H. trivolvis	3.81	5.03			
424	*L. stagnalis*	No.1 5.91	4.02			
		2 2.00	< el			
		3 2.00	< el			
		4 2.00	< el			
		5 5.03	6.80	positive		
		6 2.01	< el			
		7 2.01	< el			
		8 2.00	< el			

Table 5. (concluded). Dieldrin concentrations in Gastropoda of D slough.

Days after Application	Species	Sample & Size (g)	Dieldrin Concentration (ppb)	MC*	Confirmation SE30+	BF_3 Etherate
	L. elodes	2.02	< el			
	H. trivolvis	2.01	2.07	negative		

* Microcoulometric.
\+ Varian Aerograph 2100 using 3% SE-30 on 100/120 mesh Aeropak 30 column packing.
** Below experimental limits of detection.

Table 6. Dieldrin concentrations in Corixidae of D slough.

Days after Application	Species or Group	Sample & Size (g)	Dieldrin Concentration (ppb)	MC*	Confirmation SE30+	BF_3 Etherate
2	*Callicorixa audeni*	No.1 2.00	51.37		positive	
		2 2.00	55.45		positive	
		3 2.00	182.81		positive	
		4 2.00	156.58			
21	4 species++	1.14	35.66			
48	*C. audeni*	No.1 2.39	11.99	positive		
		2 1.94	18.44			positive
313	*C. audeni*	0.58	< el**			
349	immatures	1.96	< el			
	C. audeni	3.79	< el			
376	*C. audeni*	No.1 1.96	< el			
		2 3.20	< el			
424	*C. audeni*	No.1 2.52	< el			
		2 2.87	< el			

* Microcoulometric.
\+ Varian Aerograph 2100 using 3% SE-30 on 100/120 mesh Aeropak 30 column packing.
** Below experimental limits of detection.
\++ *C. audeni, C. alaskensis, H. atopodonta, S. decoratella.*

Dieldrin residues in larval Chironomidae are given in Table 8. Highest concentrations were reached 21 days after application. Residues were still detectable in primary consumers at the end of the study. It is likely that residues were not detected in the secondary consumers (Tanypodinae) because of the small sample sizes.

Species of Hirudinea analyzed are shown in Table 9 and the results of the analyses in Table 10. The sample for 349 days after application (July 4, 1968) was too small to yield a detectable dieldrin level. Maximum residue concentrations were reached 21 days after application, the first date after application that leeches could be collected, and were still present when the study ended.

Table 7. Dieldrin concentrations in *Notonecta undulata* of D slough.

Days after Application	Life Stage	Sample & Size (g)	Dieldrin Concentration (ppb)	Confirmation MC*	Confirmation BF_3 Etherate
2	adults	2.63	88.42	positive	positive
21	adults	2.40	45.27		
48	adults	0.38	37.11		
376	adults	2.57	< el+	negative	
424	adults	0.39	< el		
376	immatures	No.1 3.18	2.17		
		2 2.42	1.62		

* Microcoulometric.
\+ Below experimental limits of detection.

Table 8. Dieldrin concentrations in larval Chironomidae of D slough.

Days after Application	Genus	Sample Size (g)	Dieldrin Concentration (ppb)	Confirmation MC*	Confirmation BF_3 Etherate
	Primary Consumers:				
2	*Chironomus*	0.84	44.13	positive	positive
6 & 13**	5 genera+	0.81	64.45		positive
21	7 genera++	0.10	82.75		
48	5 genera+++	0.21	34.24		
313	*Chironomus*	1.44	9.84		
343	*Chironomus*	6.05	11.86	positive	
349	*Chironomus* & *Glyptotendipes*	1.80	5.10		
362	*Chironomus* & *Glyptotendipes*	2.66	7.64		
376	*Chironomus*	2.23	4.99		
	Glyptotendipes	5.61	6.89	positive	
378	*Chironomus*	4.40	6.67		
390	*Chironomus*	3.32	4.26		
424	*Glyptotendipes*	4.51	2.95		
	Secondary Consumers:				
313	*Psectrotanypus*	0.07	< el†		

Table 8. (concluded). Dieldrin concentrations in larval Chironomidae of D slough.

Days after Application	Genus	Sample Size (g)	Dieldrin Concentration (ppb)	Confirmation MC*	Confirmation BF_3 Etherate
349	*Psectrotanypus*	0.44	< el		
376	*Psectrotanypus*	0.11	< el		
424	*Psectrotanypus*	0.39	< el		

* Microcoulometric.
** These two dates were combined.
\+ *Chironomus, Dicrotendipes, Einfeldia pagana & pectoralis* grps., *Glyptotendipes, Paratanytarsus.*
++ *Acricotopus, Chironomus, Glyptotendipes, Parachironomus, Cricotopus ("Paratrichocladius"* type*), Psectrocladius,* unidentified Orthocladiinae genus.
+++ *Chironomus, Dicrotendipes, Endochironomus, Glyptotendipes, Psectrocladius.*
† Below experimental limits of detection.

Table 9. Species of Hirudinea used in gas chromatographic analyses of dieldrin concentrations in D slough.

Days after Application	Family	Species in Sample
21	Erpobdellidae Glossiphoniidae	*Erpobdella punctata* Leidy, *Mooreobdella fervida* (Verrill) *Glossiphonia complanata* (L.), *Helobdella fusca* (Castle), *H. stagnalis* (L.), *Theromyzon* sp.
48	Erpobdellidae Glossiphoniidae	*E. punctata, M. fervida* *G. complanata, H. fusca, Theromyzon* sp.
349	Glossiphoniidae	*G. complanata, H. fusca, Oculobdella lucida* Meyer and Moore, *Theromyzon* sp.
376	Glossiphoniidae	*G. complanata, H. fusca, O. lucida, Theromyzon* sp.
424	Erpobdellidae & Glossiphoniidae	*M. fervida* *G. complanata, H. fusca, H. stagnalis, O. lucida, Theromyzon* sp.

Names of Zygoptera and Libellulidae used in gas chromatographic analyses for each date are given in Tables 11 and 12. Results of the analyses of Odonata are shown in Table 13. Residues reached maximum concentrations in Anisoptera in 21 days and in Zygoptera 2 days after application. Residues were still present at the end of the study.

Names of larval and adult Dytiscidae used in gas chromatographic analyses for each date are given in Tables 14 and 15. The results of these analyses are given in Table 16. As with the adult Corixidae and Notonectidae, adult Dytiscidae are capable of moving in and out of habitats. Therefore, the origin of the high residue value in the sample from 376 days after application (July 31, 1968) is questionable. Maximum residues occurred in the larvae 2 days after application and in the adults 48 days after application. Residues were still present in both life stages at the end of the study.

Table 10. Dieldrin concentrations in Hirudinea of D slough.

Days after Application	Family	Sample Size (g)	Dieldrin Concentration (ppb)	Confirmation MC*	Confirmation BF_3 Etherate
21	Erpobdellidae	0.72	71.41	positive	
	Glossiphoniidae	0.39	131.42		
48	Erpobdellidae	1.36	46.65		positive+
	Glossiphoniidae	1.39	58.11	positive	positive
349	Glossiphoniidae	0.28	<el†		
376	Glossiphoniidae	1.92	4.56		
424	Erpobdellidae & Glossiphoniidae	3.84	3.73		

* Microcoulometric.
\+ Unclear.
† Below experimental limits of detection.

Table 11. Species of Libellulidae used in gas chromatographic analyses of dieldrin concentrations in D slough.

Days after Application	Species in Sample
2	*Leucorrhinia intacta* Hagen, *Sympetrum costiferum* (Hagen), *S. internum* Montgomery
21	*L. intacta, S. costiferum, S. internum*
48	*L. intacta*
349	*S. costiferum*
376	*S. costiferum*

Table 12. Species of Zygoptera used in gas chromatographic analyses of dieldrin concentrations in D slough.

Days after Application	Taxon	Species in Sample
2	*Enallagma-Coenagrion*	*Coenagrion angulatum* Walker, *C. resolutum* Hagen, *Enallagma cyathigerum* (Charpentier), *E. hageni* (Walsh), *Enallagma-Coenagrion*
21	*Enallagma-Coenagrion*	*C. angulatum, C. resoutum, E. cyathigerum, E. hageni, Enallagma-Coenagrion*
48	*Enallagma-Coenagrion*	*C. angulatum, C. resolutum, E. civile* (Hagen), *E. cyathigerum, E. hageni, C. resolutum-E. cyathigerum, Enallagma-Coenagrion*
313	*Enallagma-Coenagrion*	*C. angulatum, C. resolutum, E. civile, E. cyathigerum, C. resolutum-E. cyathigerum, Enallagma-Coenagrion*

Table 12. (concluded). Species of Zygoptera used in gas chromatographic analyses of dieldrin concentrations in D slough.

Days after Application	Taxon	Species in Sample
349	Zygoptera	Lestidae: *Lestes congener* Hagen, *L. disjunctus* Selys; Coenagrionidae: *C. angulatum, C. resolutum, E. civile, E. cyathigerum, C. resolutum-E. cyathigerum, Enallagma-Coenagrion*
376	*Enallagma-Coenagrion*	*C. angulatum, C. resolutum, E. cyathigerum, C. resolutum-E. cyathigerum, Enallagma-Coenagrion*
424	*Enallagma-Coenagrion*	*C. angulatum, C. resolutum, E. cyathigerum, E. hageni, C. resolutum-E. cyathigerum, Enallagma-Coenagrion*

Table 13. Dieldrin concentrations in larval Odonata of D slough.

Days after Application	Taxon		Sample Size (g)	Dieldrin Concentration (ppb)	Confirmation BF_3 Etherate
	A. *Aeshna interrupta*				
2			1.26	10.36	
21			1.34	36.37	positive
48			1.12	8.89	
313			1.95	2.63	
349			4.26	3.95	positive
376			1.06	3.15	
	B. Libellulidae				
2			2.12	82.83	
21			1.13	87.17	positive
48			0.94	8.15	
349			3.25	4.09	
376			1.34	4.38	
	C. Zygoptera				
2	*Lestes congener*	No.1	1.81	56.76	
		2	2.51	45.30	positive
		3	2.79	32.08	
	L. disjunctus		1.09	32.13	
	Enallagma-Coenagrion		0.29	35.04	
21	*L. congener*		0.90	9.31	
	Enallagma-Coenagrion		2.14	22.45	
48	*Enallagma-Coenagrion*		4.09	8.23	
313	*Enallagma-Coenagrion*		3.26	1.91	
349	mixture		1.58	0.68	
376	*Enallagma-Coenagrion*		0.59	7.57	
424	*Enallagma-Coenagrion*		1.37	1.83	

Table 14. Genera of Dytiscidae larvae used in gas chromatographic analyses of dieldrin concentrations in D slough.

Days after Application	Genera in Sample
2	*Agabus, Dytiscus, Graphoderus, Laccophilus, Rhantus* or *Colymbetes*
313	*Agabus, Graphoderus, Rhantus* or *Colymbetes*
349	*Agabus, Graphoderus, Hydroporus* or *Hygrotus, Laccophilus, Rhantus* or *Colymbetes*
376	*Laccophilus, Rhantus* or *Colymbetes*

Table 15. Species of Dytiscidae adults used in gas chromatographic analyses of dieldrin concentrations in D slough.

Days after Application	Species in Sample
2	*Colymbetes sculptilis* Harr., *Graphoderus perplexus* Shp., *Hygrotus dispar* Lec., *Rhantus frontalis* Marsh
21	*C. sculptilis, Dytiscus ooligbucki* Kby., *G. perplexus, R. frontalis*
48	*C. sculptilis, R. consimilis* Mots., *R. frontalis*
313	*Agabus antennatus* Leech, *C. sculptilis, D. ooligbucki, H. dispar, Illybius subaeneus* Er., *Laccophilus biguttatus* Kby., *R. consimilis, R. frontalis, R. wallisi* Hatch
349	*Acilius semisulcatus?* Aubé, *C. sculptilis, G. occidentalis* Horn, *G. perplexus, H. sayi* Balf.-Br., *R. consimilis, R. frontalis*
376	*C. sculptilis, G. occidentalis, G. perplexus, H. dispar, I. subaeneus, L. biguttatus, R. frontalis*

Table 16. Dieldrin concentrations in Dytiscidae of D slough.

Days after Application	Sample Size (g)	Dieldrin Concentration (ppb)	Confirmation BF_3 Etherate
	A. Larvae		
2	0.61	112.02	positive
313	0.10	24.65	
349	0.93	22.96	positive
376	0.79	6.40	
	B. Adults		
2	1.25	99.02	
21	2.04	110.42	positive
48	0.77	142.63	
313	3.07	43.95	
349	1.41	16.41	
376	1.07	44.63	positive

95% confidence limits for sampling dates which have three or more replicates of the same type of sample (for all environmental components of the study) are given in Table 17. The reader's attention is drawn to the excellent reviews of Kenaga (1972, 1973) and Moriarty (1972) for a discussion of the factors that can cause variability in determinations of pesticide residues.

Table 17. 95% confidence limits for dieldrin concentrations in mud, water, vegetation, and invertebrates from sampling dates with three replicates or more.

Material	Sample Date	Mean Concentration (ppb) & 95% Confidence Limits
mud	July 22, 1967	4.15 ± 2.06
	Sept. 6, 1967	0.61 ± 1.93
water	July 22, 1967	0.35 ± 0.99
vegetation		
–emergent*	July 22, 1967	7.51 ± 4.89
–submergent**	July 22, 1967	40.28 ± 19.57
	Aug. 10, 1967	23.61 ± 7.06
	Sept. 6, 1968	1.71 ± 1.88
invertebrates		
–*L. stagnalis*	July 23, 1967	150.98 ± 35.31
	Aug. 11, 1967	113.22 ± 52.93
–*C. audeni*	July 23, 1967	111.55 ±108.12
–Zygoptera	July 23, 1967	40.26 ± 13.29

* *C. rostrata*

** *C. demersum* and *L. trisulca*

DISCUSSION

Table 18 summarizes some parameters of this and other studies done on the fate of the chlorinated hydrocarbons added to whole ecosystems. It compares times at which maximum concentrations are reached and pesticide is no longer detectable in mud and/or sediment. "Length of Time until Maximum Concentration" should be interpreted with caution because the different authors did not use equivalent time intervals in their analyses. Maximum concentration has been used here because, for most studies, the actual amount of pesticide that entered the water after application is not known[4]. Data are insufficient to correlate maximum concentration with length of time until residues were undetectable. However, an indication exists that lower concentrations became undetectable faster (see Croker and Wilson, 1965). Again, caution should be used in drawing such conclusions because sensitivity of most of the analytical methods used is unknown.

It is apparent from Table 19 that maximum concentrations and the time until residues are detectable are reached sooner in water than in any other ecosystem component and these rates would seem to be independent of initial concentration. The maximum mean concentration of 0.35 ppb in the water of D slough was below the concentration intended (1.0 ppb). However, Bridges et al. (1963) and Meeks (1968) showed that the maximum concentration of DDT in the water samples studied by them was reached in the first hour after treatment

4. In both Vaajakorpi and Salonen (1973) and this study the insecticide was added below the water surface.

and by the following day, levels were approximately 1/25 and 1/2 the maximum concentration respectively. Thus, almost certainly the maximum concentration of dieldrin in the water of D slough was greater than 0.35 ppb. The rapid decline of chlorinated hydrocarbon concentrations is due to two major processes: their relative insolubility in water, compared to organic matter, which causes them to preferentially attach to organic matter and be removed from the water (e.g. by settling to the bottom) (Edwards, 1970; Muirhead-Thomson, 1971; Cope, 1971) and co-distillation (Eberhardt, Meeks, and Peterle, 1971).

Table 18. Some parameters of and decline of chlorinated hydrocarbon pesticide residues in mud and/or sediment of studies cited.

Reference	Pesticide Used	Application Rate	Maximum Concentration	Time to Maximum Concentration	Time until Residues Undetectable
Bridges (1961)	endrin	6 oz/acre	0.80 ppm	53 days*	61-75 days
Bridges et al. (1963)	DDT	0.02 ppm in water	8.30 ppm	1 day	No mud samples taken after 8 weeks; level at that time: 0.19 ppm.
Edwards et al. (1964)	DDD	1.0 lb/acre	1.02 lb/acre	7 days	Study terminated after 9 months; level at that time: 0.12 lb/acre.
Croker and Wilson (1965)	DDT	0.2 lb/acre	3.35 ppm	6 weeks	Study terminated after 11 weeks; level at that time: 0.76 ppm.
Meeks (1968)	DDT-Cl^{36}	0.2 lb/acre	Not applicable. Topsoil analyzed.		
Vaajakorpi and Salonen (1973)	DDT-^{14}C	1 mg/m^3 (i.e. 1 ppb in water)	1.12 ppm	1 day	Study terminated after 59 days; level at that time: 0.71 ppm.
this study	dieldrin	1.0 ppb in water	4.15 ppb	1 day	7-29 weeks

* Mud not sampled until 16 days after application of endrin.

Bridges et al. (1963) and Meeks (1968) continued to detect residue levels in submergent and emergent vegetation in the year following application whereas I did not (Table 20). [The maximum concentrations given for Meeks (1968) and Vaajakorpi and Salonen (1973) are the highest of the species of submergent and emergent vegetation analyzed. For Meeks (1968), the length of time until residues could not be detected is the time of the final sample for the species which had the lowest level of pesticide]. This could be a function of the low initial concentration of my study. As in Meeks (1968), submergent vegetation of my study had higher levels of residues than emergent. This is a function of the surface area available for the pesticides to be adsorbed (Meeks and Peterle, 1967). Among the studies in Table 20

Table 19. Decline of chlorinated hydrocarbon pesticide residues in water of studies cited.

Reference	Maximum Concentration of Pesticide (ppm)	Time to Maximum Concentration	Time until Residues Undetectable
Bridges (1961)	0.04	4 days+	26 to 34 days
Bridges et al. (1963)	0.08	30 min	3 to 4 weeks
Edwards et al. (1964)	0.05 to 0.10	1 day	2 weeks
Croker and Wilson (1965)*	0.05	1 day	5 to 7 days
Meeks (1968)	0.003	1 hr	2 weeks to 1 month
Vaajakorpi and Salonen (1973)	0.86	12 hr	Study terminated at 59 days; level at that time: 0.01 ppm.
this study	approx. 0.00035	1 day	2 to 3 weeks

\+ Water not sampled until 4 days after endrin applied.
* This data: from holding sites. (See original publication).

Table 20. Decline of chlorinated hydrocarbon pesticide residues in submergent and emergent vegetation of studies cited.

Reference	Type of Vegetation Sub.	Em.	Maximum Concentration (ppm)	Time to Maximum Concentration	Time until Residues Undetectable
Bridges (1961)	+		0.55	16 days*	44 to 53 days
Bridges et al. (1963)	+		30.7	30 min	Study terminated after 12 months; level: 0.6 ppm (pre-treatment level: 0.8 ppm). Therefore, 8 weeks to 12 months.
Croker and Wilson (1965)	+		75.0	3 to 4 weeks	No samples taken after 7 weeks; level: 9.1 ppm.
Meeks (1968)†	+		96.1 (*Cladophora* sp.)	3 days**	Study terminated after 15 months; level: 0.1 ppm.
		+	11.4 (*Sagittaria latifolia* Willd.)	1 day	Study terminated after 15 months; level: 0.1 ppm.
Vaajakorpi and Salonen (1973)	+		7.25 (*Utricularia* sp.)	2 days	No samples of *Utricularia* sp. taken after 30 days; level: 1.98 ppm. Study terminated after 59 days; level in *Drepanocladius* sp.: 0.22 ppm.
this study	+		0.0408	1 day	47 to 323 days
		+	0.0075	1 day	20 to 47 days

* No vegetation samples taken until 16 days after endrin applied.
** Sample not taken until 3 days after application.
† See discussion in text.

"Time to Maximum Concentration" varies but indications are that it occurs within the first day after application. Also, there are indications that the higher initial concentrations persist longer than the lower ones.

Undoubtedly, the initial high concentration of dieldrin in zooplankton was due to the high surface to volume ratio of zooplankton (Kenaga, 1973). Crosby and Tucker (1971) reported accumulations of DDT from dilute suspensions in water of 16,000 to 23,000 times by *Daphnia magna* Strauss. Wojtalik, Hall, and Hill (1971) reported uptake of high concentrations of 2, 4-D by plankters. Johnson et al. (1971) reported the rapid direct uptake of aldrin and DDT from water by the freshwater invertebrates of their study and that *D. magna* and *Culex pipiens* L. showed the greatest degree of magnification. Sanders and Chandler (1972) found that *D. magna* had the highest magnification factor of the eight species of invertebrates exposed to PCB's in the ppb range. Hughes and Lee (1973) reported that net plankton accumulated large amounts of toxaphene. The differential solubility of chlorinated hydrocarbon insecticides causes them to move directly to organic matter as soon as they are applied to water (Dustman and Stickel, 1969; Edwards, 1970; Muirhead-Thomson, 1971; Cope, 1971) and it has been shown that these hydrophobic compounds adhere to suspended organic particles in the water (Nicholson, 1967; Stickel, 1968; Wurster, 1969; Edwards, 1970). Vaajakorpi and Salonen (1973) showed that 3 μ diameter seston had higher DDT concentrations than 8 μ diameter seston and had the highest DDT concentrations of any of the ecosystem components they analyzed. Reinert (1967) showed that *Daphnia* accumulated more dieldrin from water than from food. Plankton, therefore, merely serve as immediately accessible suspended organic particles to which chlorinated hydrocarbons move directly when applied to water. In fact, because of their lipid content, greater chlorinated hydrocarbon deposition may occur in plankton than in other organic seston (Cope, 1971; see also Kawatski and Schmulbach, 1971).

Residues in the planorbids and *Lymnaea* sp. of Meeks' (1968) study reached a maximum concentration 1 and 3 days respectively after application of the DDT-Cl^{36}. The snails of my study reached maximum observed residue concentrations on the first sampling date, which was 2 days after application. Maximum concentrations in Meeks' study were among the lowest of all the invertebrates. Those of the *L. stagnalis* of my study were second only to the zooplankton. I used only soft tissues for analysis whereas Meeks probably used the whole body. Because the shell is such a large percentage of the total weight, and because later analyses by Meeks of planorbids showed the shells had no residues, the concentrations reported by Meeks are likely underestimates. Meeks reported the presence of residues in both kinds of snails at the end of the study (13 months after application). Levels were still detectable in *L. stagnalis* and *H. trivolvis* at the end of my study (approximately 14 months after application).

Residues in notonectids of Meeks' (1968) and Vaajakorpi and Salonen's (1973) studies were at a maximum 1 week and 2 to 4 days respectively after application of the DDT. In my study, maximum concentrations were reached in adults on the second day after application. Meeks recorded no residue levels in the notonectid samples he studied in the second and twelfth months after application, and a relatively low level in the thirteenth month. Vaajakorpi and Salonen continued to detect DDT in *Notonecta* sp. until their last sampling (30 days after application). Neither works indicated whether the notonectids were adults or immatures. Because adult corixids and notonectids can fly, their reliability as indicators of pesticide levels in habitats is questionable. Similar rationale (i.e. that movement of the indicator organism be restricted to the area under study) was used by Gish (1970), Foehrenbach (1972), and Coulson et al. (1972) in choosing the indicator species of their studies.

The maximum concentration of residues in the bloodworm (*Tendipes* sp.) of Meeks' (1968) study was reached 1 week after application. In my study, maximum concentration was reached

in 3 weeks. This delay was also shown by the Libellulidae, *Aeshna interrupta* Walker, and adult Dytiscidae of my study (see below). Unfortunately, analysis of chironomids in Meeks (1968) was ended 1 month after application. The residues in the chironomid primary consumers of my study were still detectable at the end of the study (approximately 14 months after application).

Meeks (1968) analyzed *Erpobdella punctata,* a species of Hirudinea present in D slough and used in my analyses of residues (see Table 9). He reported that a maximum concentration of residue was reached 2 weeks after application of the pesticide and that *E. punctata* had the highest residues of all the invertebrates analyzed. In my study, the Erpobdellidae, the family to which *E. punctata* belongs, had lower residue levels in general than the Glossiphoniidae and the leeches did not have the highest residues of the invertebrates. Residues were still present in leeches of both studies when the studies were terminated (Meeks' – 15 months; and mine – approximately 14 months after application).

Residues in the Anisoptera and Zygoptera larvae of Meeks' (1968) study reached maximum concentrations 1 week after pesticide application. Vaajakorpi and Salonen (1973) reported maximum concentrations in Odonata larvae 2 weeks after application of the DDT. In my study, maximum concentrations were detected in Anisoptera in 3 weeks and in Zygoptera in 2 days. Residues were still present in the Odonata at the termination of the studies (Meeks' – 13 months; Vaajakorpi and Salonen's – 59 days; and mine – 14 months after application).

Neither Meeks (1968) nor Vaajakorpi and Salonen (1973) presented any data for Dytiscidae.

Tables 21 and 22 show maximum and final pesticide concentrations of primary and secondary consumers in Meeks (1968), Vaajakorpi and Salonen (1973), and this study. (I hesitate to accept the results of the adult Dytiscidae analyses shown in Table 22 because they are the only group that showed a dramatic rise at the end of the study; and because they are capable of entering and leaving the slough so their role as indicators of pesticide relationships in the slough is open to question). It is evident from these tables that similar ranges of pesticide concentrations exist between primary and secondary consumers. The reality of food chain concentration of chlorinated hydrocarbon insecticides in invertebrate communities is discussed in Rosenberg (1975).

Table 21. Maximum and final DDT concentrations (ppm) in invertebrates of Meeks (1968) and Vaajakorpi and Salonen (1973).

Taxon	Maximum Concentration	Final Concentration
Primary consumers:		
Gastropoda – Planorbidae	1.1	0.2
– *Lymnaea* sp.	2.2	1.2
+Pelecypoda – *Sphaerium* sp.	3.0	0.2
+Trichoptera	1.7	0.4
Chironomidae	5.2	2.0
Erpobdellidae*	12.6	2.3
Amphipoda	6.2	0
crayfish	3.8	0.3
Secondary consumers:		
Notonectidae	3.2	0.2
+*Notonecta* sp.	0.3	0.2
Odonata – Zygoptera	3.8	0.9
– Anisoptera	1.7	0.2
+Odonata (unspecified)	0.5	0.2

* Arbitrarily called primary consumers. They are scavengers or feed on aquatic invertebrates (Pennak, 1953; A. R. Smith, Alberta Department of Lands and Forests, Fish and Wildlife Division, Edmonton, Alberta; unpublished). That is, they are "opportunistic" feeders.

\+ From Vaajakorpi and Salonen (1973). The other data are from Meeks (1968).

Table 22. Maximum and final dieldrin concentrations (ppb) in invertebrates of this study.

Taxon	Maximum Concentration	Final Concentration
Primary consumers:		
zooplankton	362.9	5.3
Gastropoda – *L. stagnalis*	151.0	5.4
– *L. elodes*	47.4	9.4
– *H. trivolvis*	51.8	2.1
Corixidae (adults)	111.6	15.2
Chironomidae – mixture	82.8	
– *Chironomus*	44.1	4.3
– *Glyptotendipes*		3.0
Erpobdellidae	71.4	3.7
Secondary consumers:		
Glossiphoniidae	131.4	3.7
Notonectidae – adults	88.4	< el∞
– immatures		2.2
Odonata – Zygoptera	37.3	1.8
– Libellulidae	87.2	4.4
– *Aeschna interrupta*	36.4	3.2
Dytiscidae – adults	142.6	44.6
– larvae	112.0	6.4

∞ Below experimental limits of detection.

The decline of dieldrin concentrations in mud, water, vegetation, and invertebrates of D slough is a result of complex interactions of physical and biological processes. This subject is reviewed in Rosenberg (1973). In general, the declines of dieldrin residues in mud, water, vegetation, and invertebrates in D slough follows the form of the first order kinetics model described for acute applications by Eberhardt et al. (1971). [See Rosenberg (1973) for graphs of dieldrin declines in the ecosystem components discussed above]. Cooke (1973) noted that repeated (chronic) dosing would cause a greater proportion of the pesticide to be stored in fatty tissues from which residues would be lost slowly whereas in a single (acute) dose the residues are lost quickly because only low concentrations are accumulated in the fat. Residues in the ecosystem components of this study, therefore, are mostly in the "fast compartment" of Eberhardt et al.'s (1971) model.

SUMMARY AND CONCLUSIONS

1. Levels of dieldrin were below detection in mud, water, and vegetation of D slough after 47 days after application. Dieldrin levels were detectable in zooplankton, Gastropoda, larval Chironomidae, Hirudinea, larval Odonata, and larval and adult Dytiscidae at the end of the study (≅ 1 year) but were below detection in adult Corixidae and Notonectidae before the end of the study.
2. Zooplankton had the highest initial concentration of dieldrin of any ecosystem constituent.
3. Mud, water, vegetation, and primary and secondary invertebrate consumers carried similar levels of dieldrin in their tissues.

4. Dieldrin residues in mud, water, vegetation, and invertebrates of D slough declined according to a first order kinetics equation, as found by other authors. These declines were influenced by the hydrophobic nature of chlorinated hydrocarbons and the interaction of physical and biological processes.
5. The fate of chlorinated hydrocarbon insecticides in other small, standing water ecosystems was similar to the fate of dieldrin in the ecosystem of this study.

ACKNOWLEDGEMENTS

I would like to thank W. G. Evans whose original concept formed the basis of this study; for his advice, continual encouragement, and the many helpful discussions we have had. Thanks are also due to the other members of my advisory committee for their help in producing the thesis which formed the basis of this paper: G. E. Ball, Department of Entomology, University of Alberta; H. F. Clifford and J. R. Nursall, both of the Department of Zoology, University of Alberta; and W. F. Allen, Department of Chemistry, University of Alberta. F. A. J. Armstrong, M. Healey, and R. D. Hamilton of the Freshwater Institute, Winnipeg, G. R. B. Webster, Pesticide Research Unit, University of Manitoba, and D. Pimentel, Cornell University, critically read the manuscript. I have used many of their suggestions.

I am indebted to the people who helped me identify the invertebrates of this study: J. R. Morris (Gastropoda), Department of Zoology, University of Alberta; A. R. Smith (Hirudinea), Alberta Department of Lands and Forests, Fish and Wildlife Division, Edmonton, Alberta; J. S. Carr (Coleoptera), R.R. No. 4, Calgary, Alberta; A. L. Hamilton and O. A. Saether (Chironomidae), both of the Fisheries Research Board of Canada, Freshwater Institute, Winnipeg, Manitoba; P. S. Corbet (Odonata), Department of Biology, University of Waterloo, Waterloo, Ontario.

V. W. Kadis, O. J. Jonasson, W. Currie, and W. Breitkreitz, all of the Alberta Department of Agriculture, Dairy and Food Laboratory, Edmonton, Alberta, gave me considerable help and advice with the gas chromatographic aspects of the study.

L. L. Kennedy and M. Dumais, both of the Department of Botany, University of Alberta, identified plants; and D. Christophel, Department of Botany, University of Alberta, helped describe the study site from an eco-botanical aspect.

H. Hall, L. Hill, T. McMahon, K. Morgan, W. Skrlac, and D. Wales provided technical help.

Special thanks are due to R. Henschel and D. Swanek for letting me work on their properties.

G. Porth and C. Plumridge, Freshwater Institute, Winnipeg, typed drafts of the manuscript. A. P. Wiens and C. Madder helped proofread the drafts.

This research was supported by National Research Council of Canada and Canadian Wildlife Service grants to Dr. W. G. Evans. I am pleased to acknowledge my appreciation to the National Research Council of Canada for scholarships awarded.

APPENDIX I.
METHOD FOR THE GAS CHROMATOGRAPHIC ANALYSIS OF INVERTEBRATES

A: Apparatus and reagents – See Kadis, Jonasson, and Breitkreitz (1968) and Rosenberg (1973).

B: Procedure – Invertebrates were divided into two types for purposes of maceration: those with hard exoskeletons (e.g. Corixidae, Notonectidae, and adult Dytiscidae) and those with soft exoskeletons (e.g. Hirudinea, Gastropoda removed from their shells, zooplankton, and

Chironomidae and Odonata immatures). After surface moisture was removed from each sample by blotting with paper toweling, the former were combined with sand and anhydrous Na_2SO_4 (for 2 g invertebrate tissue, approximately 5 g sand and 10 g Na_2SO_4) and ground with the Omni-Mixer at medium speed for about 5 min or until a visually homogeneous mixture resulted (Jonasson and Rosenberg, 1969). The mixture was then added to 50 g deactivated florisil in a mortar and pestle, the Omni-Mixer cup and blades were rinsed with petroleum ether, and the rinsings were added to the mortar and pestle. The invertebrates with soft exoskeletons were ground directly in 50 g of deactivated florisil in the mortar and pestle. For soft and hard types, the mixture from the pestle was then added to a chromatographic column containing 50 g deactivated florisil prewashed with 150 ml of 1:1 methylene chloride-petroleum ether. The column was eluted with 800 ml 20:80 methylene chloride-petroleum ether. The eluant was evaporated to near dryness, made up in a suitable volume, and injected (Kadis, et al., 1968). When necessary, samples were further cleaned up on a magnesium oxide-celite column as described in Barry et al. (1968, section 211.16c) and/or by the following method: 10 g deactivated florisil sandwiched between two 2.5 cm portions of anhydrous Na_2SO_4 prewashed three times with 25 ml petroleum ether. The sample was added to the column and the column was then eluted with 150 ml 5% benzene in petroleum ether and then 200 ml of 25% benzene in petroleum ether, the second fraction containing the dieldrin.

Recovery studies were done using *Hyallela azteca* (Saussure) from the control slough. Samples spiked with 0.003 μg dieldrin (0.12×10^{-8} ppm in 2.42 g tissue) gave an average recovery of 95.2% (3 replicates).

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